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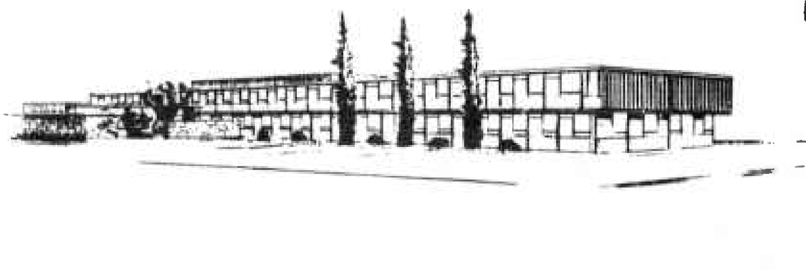
CONTRACT TECHNICAL NOTE

SOME LIMITATIONS ON THE PERFORMANCE OF HIGH-VELOCITY GUNS

CONTRACT NO. DA-04-495-ORD-3567(Z)
HYPERVELOCITY RANGE RESEARCH PROGRAM
A PART OF PROJECT "DEFENDER"

GM DEFENSE RESEARCH LABORATORIES
SANTA BARBARA, CALIFORNIA

AEROSPACE OPERATIONS DEPARTMENT



CTN64-03

AUGUST 1964

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SOME LIMITATIONS ON THE PERFORMANCE OF HIGH-VELOCITY GUNS

John S. Curtis

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SOME LIMITATIONS ON THE PERFORMANCE OF HIGH-VELOCITY GUNS

Free-flight ranges using light-gas gun launchers are an important tool in the investigation of the phenomena associated with hypersonic flight. The successful completion of space-flight projects currently planned requires that the velocity capability of research facilities be extended to reentry and even meteoric speeds. If the planning of research using free-flight ranges is to be done intelligently, it is necessary to know what the ultimate capability of light-gas gun launchers will be. However, no clearly defined theoretical upper limit to the velocity capability of a light-gas gun exists. A moderately well defined upper limit does exist for the size of projectiles which can be launched at any specified velocity in any given gun.

It is the purpose of this note to discuss the velocity regime over which the light-gas gun will be useful as a research tool. This will be done by considering the ratio of accelerating forces to the strength of the projectile.

The velocity achieved in any launcher is the product of the acceleration and the time of launch if the acceleration is constant, and it is the integral under the acceleration-time curve for variable-acceleration launches. To achieve high velocity, either acceleration or time, or both, must be large. In a light-gas gun, the accelerating force is generated by the pressure of the light gas acting on the base of the projectile. Increasing the accelerating force implies increasing gas pressure, and utlimately a pressure limit is reached. If the time of launch is increased, the length of the launch tube must be increased; the length of the launch tube is proportional to the square of the launch time for a given velocity. Thus, in order to limit the size of the gun, it is very desirable to make the acceleration, and hence the pressure, as high as possible.

Two factors operate to limit the pressure which can be used in a light-gas gun. First, and most important, the pressure applied to the base of the projectile must not be so large as to break or permanently deform the model. Second, the pressure in the gun should not overstress or destroy the gun. In general, the pressure which can be applied to a projectile of any sophistication without destroying it is an order of magnitude less than the pressure which can be withstood by a well designed gun.

In any given gun, the maximum projectile velocity will be achieved if the pressure applied to the base of the projectile is held constant at the maximum allowable value during the launching run. A gun which is able to operate in this manner is defined as an ideal gun (see Reference 1).

In an actual operating gun it is difficult, impractical, and in fact undesirable, to hold the base pressure exactly constant during the launching run. Since the ideal gun will impart the highest velocity to any given projectile, a measure of the quality of a gun can be made by comparing the performance of the actual and ideal gun at equal maximum base pressures. The ratio of the velocity obtainable in the ideal gun to the velocity obtained in the actual gun when the maximum base pressures are equal will be called the performance factor. Thus, the performance factor for any launching sequence is the ratio of maximum base pressure to the average base pressure during the launch.

A gun has been built at GM DRL with the specific objective of improving the performance factor (see Reference 2). While no actual measure of the performance factor has been made, both computations and experience with the gun indicate that it operates consistently with a performance factor of two or less. By contrast, the performance factor of early light-gas guns is near five, and that of shock-heated light-gas guns probably lies between five and seven.

Next to pressure the main constraints are the limitations on gun performance which are imposed by the projectile strength. A graph giving the combinations of acceleration and distance which combine to yield various velocities is shown in Figure 1. It will be noted that for a distance of the order of 20 feet, an acceleration of the order of one million g's is required to achieve a velocity in the region between 30,000 and 40,000 feet per second.

The compressive stresses produced in a body by an acceleration of one million g's are shown in Figure 2. The body, for simplicity, is assumed to be a right cylinder, unsupported on the sides. The accelerating force is applied to the aft end of the cylinder and is distributed uniformly across the face of the cylinder. A constant stress gradient will exist in the body and the compressive stress will vary from zero at the front face to some maximum value at the rear face. The stress at any point will depend on the density of the material, the acceleration, and the distance from the front face of the material. The slope of the curves in Figure 2 is a function of density only, and the curves have been computed for the specific materials which are so labeled. It will be noted that when accelerated in the manner specified at one million g's, the compressive stress one inch from the front face will be larger than the ultimate strength of most materials. Figure 3 is a generalization of Figure 2, wherein the stresses are shown as a function of length for a range of accelerations from 100,000 g's to 10,000,000 g's.

The usefulness of these simple curves in designing a gun for a particular experiment can best be shown by an example. Suppose we wish to launch an aerodynamic model configuration at a velocity of 40,000 feet per second. The projectile configuration can be approximated by a cylinder one inch long. From a consideration of strength-to-weight ratio and the total projectile weight, we construct the projectile of aluminum having an ultimate compressive strength of 60,000 psi. What is the minimum size gun which will successfully launch this model?

First, enter the top part of Figure 3 at a compressive stress of 60,000 psi. Move horizontally to the aluminum line, then vertically downward from this point to the curved line labeled one inch. Read on the ordinate at this point an acceleration of 620,000 g's. This is the maximum acceleration which the projectile can withstand without exceeding the ultimate strength of the material. Before entering Figure 1 to determine the size of gun necessary, we must know the average acceleration. From the definition of the performance factor, the average acceleration is equal to the maximum acceleration divided by the performance factor. Using a performance factor of two as a representative value, we get an average acceleration of 310,000 g's. Now entering Figure 1 at an acceleration of 310,000 g's, move vertically upward to the 40,000 feet per second line and at this point read the distance required on the ordinate as 82 feet. This is then the length of the barrel of the gun required.

With one major dimension of the gun fixed, it is possible to determine the remaining dimensions of the gun within reasonable limits. A barrel which has a length of 300 calibers is a long barrel in which to maintain a performance factor of 2. It is not unreasonable, however, to expect that such performance can be achieved. Using a length of 300 calibers, the diameter is then approximately 3.3 inches. For an accelerated-reservoir gun, the diameter of the pump tube should be at least four times the diameter of the launch tube; so the pump tube will have a diameter of about one foot. The length of the pump tube will be determined by the compression ratio necessary to achieve a performance factor of two.

Using the method described in the preceding example, Figure 4 has been prepared showing the length of gun barrel required to launch aluminum cylinders of varous lengths at various velocities. From this figure it is apparent that it will require a very large gun to launch an aluminum projectile whose equivalent length is one inch at a velocity near 40,000 feet per second. (Equivalent length is defined as the length of a cylinder of the same material and weight in which the maximum compressive stress will be the same as that in the projectile when fired under the same conditions.)

The curves are also useful in determining the maximum velocity at which a projectile of a given length can be launched in a specified gun. Figure 3 and the performance factor are used as before, but Figure 2 is entered using the barrel length as the distance and the acceleration obtained from Figure 3.

A rough check on the validity of this approach has been obtained in the Ballistics Range at GM Defense Research Laboratories. Two projectiles have been fired a sufficient number of times to determine the approximate upper limit to the velocity with which they can be launched intact using a .22-caliber launch tube four feet long. The projectiles are a 3/16-inch-diameter solid aluminum sphere and a 1/8-inch-diameter solid glass sphere. Using 60,000 psi and 50,000 psi, respectively, as the maximum allowable compressive strengths and an equivalent projectile length of 2/3 diameter, the maximum velocities obtained from Figures 2 and 3 are 25,000 feet per second and 29,000 feet per second, respectively. The highest velocity at which a successful launch has been made using these projectiles is 22,000 and 26,700 feet per second, respectively. The agreement is quite satisfactory considering the very simple approach taken.

This analysis leads to three direct conclusions:

1. If the size and properties of the projectile are constant, the minimum linear dimensions of a gun necessary to launch the projectile are proportional to the square of the launch velocity, and the mass of the gun or any gun part is proportional to the sixth power of the launch velocity.

2. If the velocity of the launch is constant, the minimum linear dimensions of a gun necessary for successful launch are directly proportional to the length of the projectile, and the mass of the gun or any gun part is proportional to the cube of the length of the projectile.

3. If the size of the gun is constant, the length of the projectile which can be successfully launched is inversely proportional to the square of the launch velocity.

It is thus apparent that the size of gun necessary for any test is a critical function of the velocity of the test and the size of the projectile. Also, if free-flight range testing is to be done at a velocity of 40, 000 feet per second, the size of the model must be small regardless of the size of the gun.

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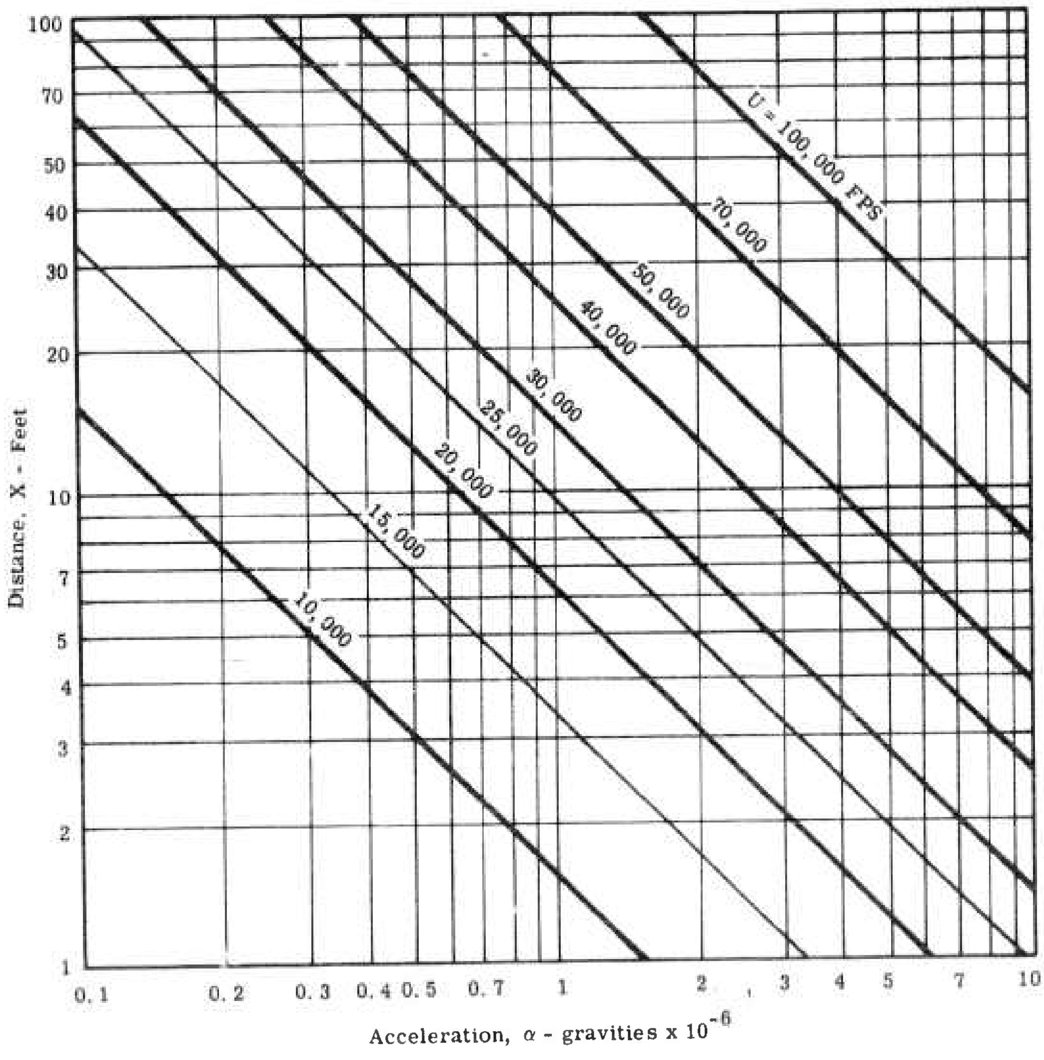

Figure 1 Velocity – Distance Relationship at Constant Acceleration.

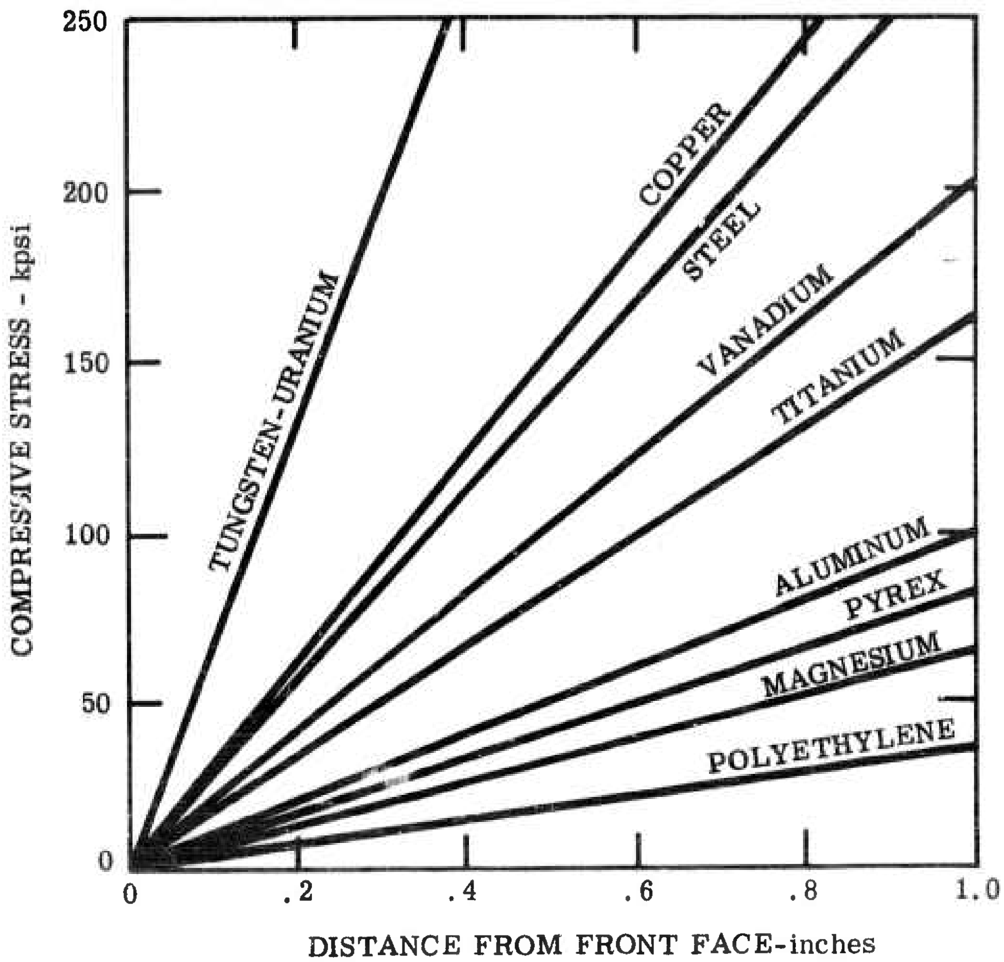

Figure 2 Compressive Stress as a Function of Distance From Front of a Cylindrical Projectile Accelerated by a Force Applied to One End, Resulting in an Acceleration of One Million Gravities

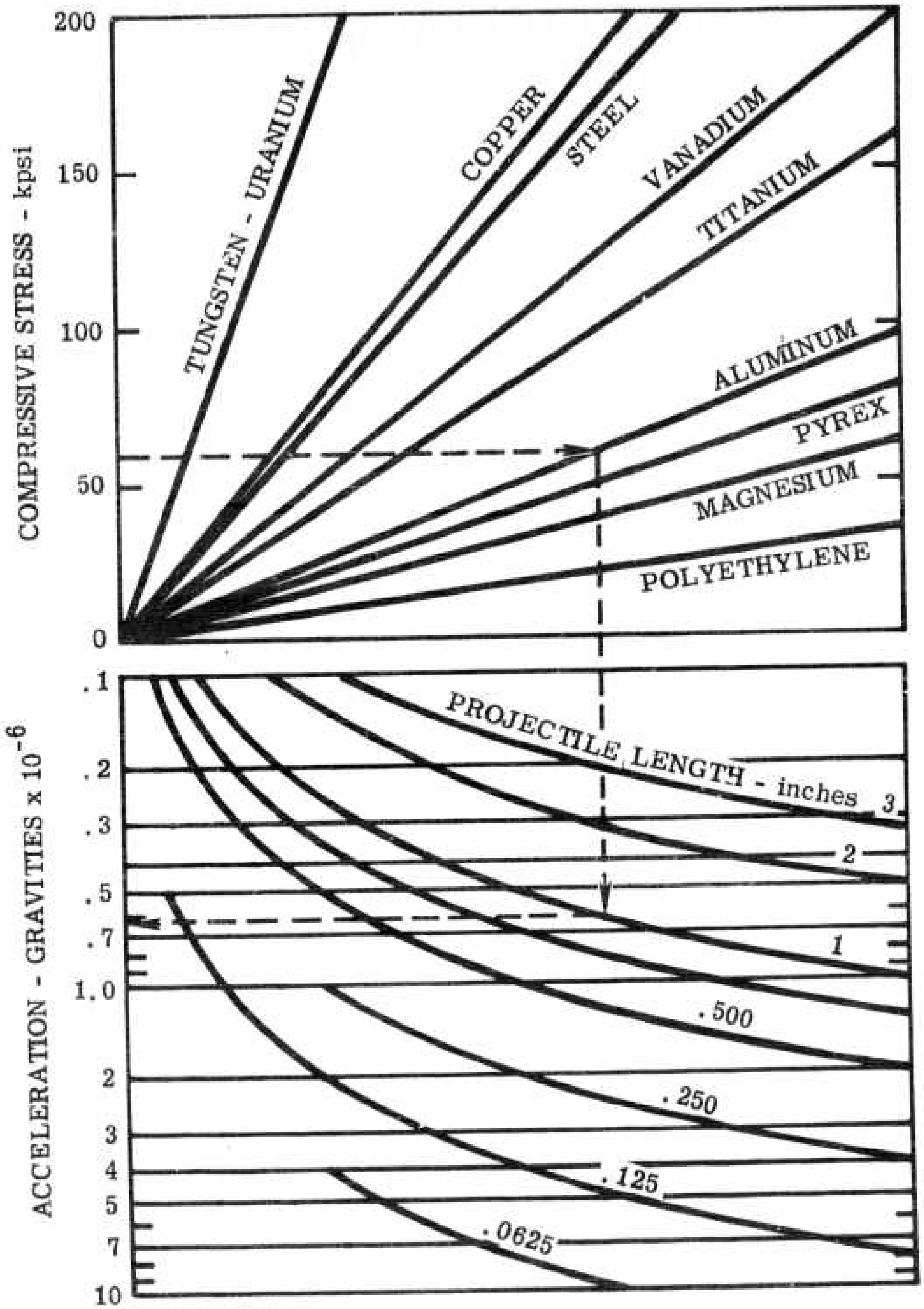

Figure 3 Nomograph

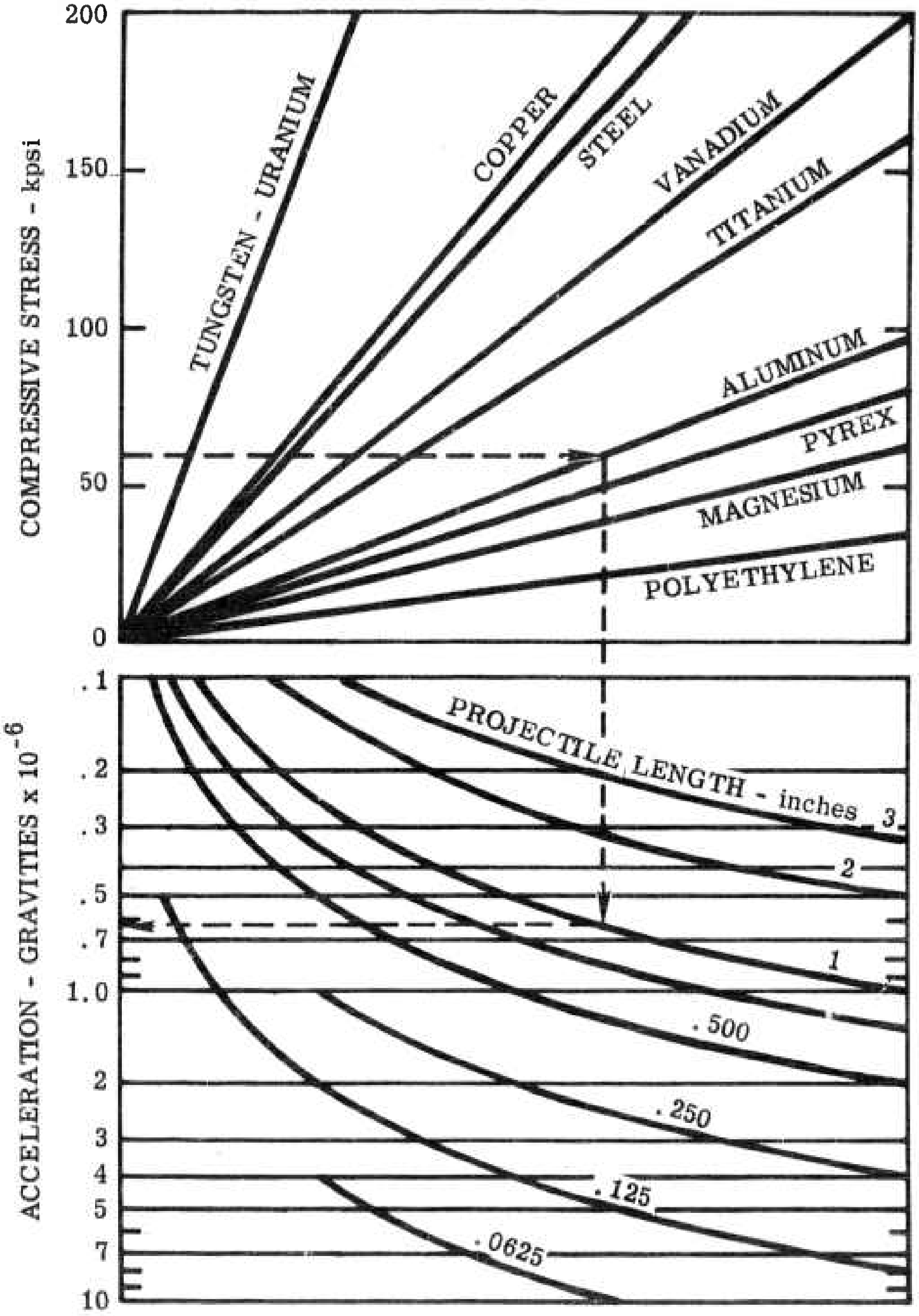

Figure 3 Nomograph

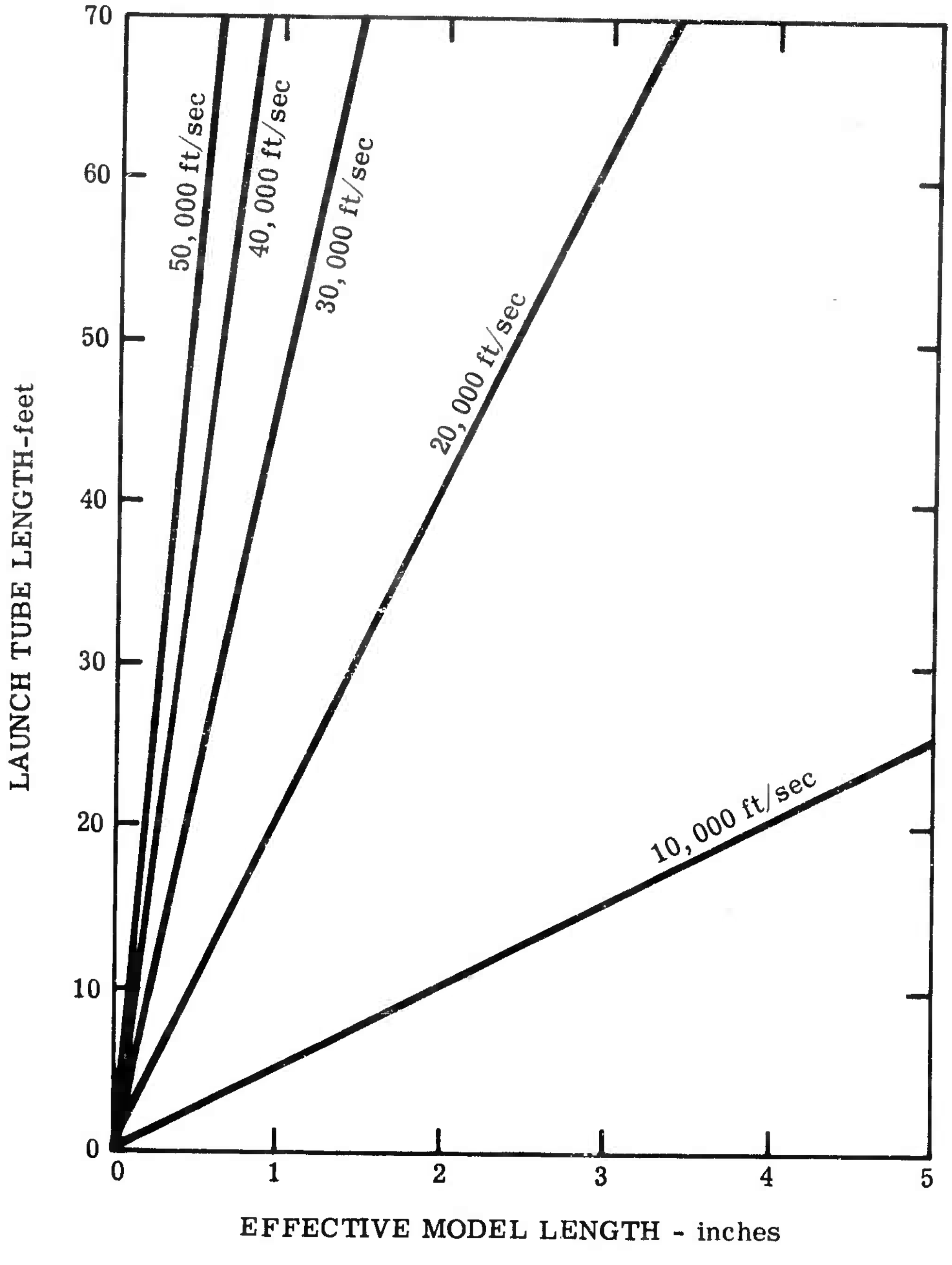

Figure 4 Launch Tube Length Required to Launch Aluminum Models of Various Effective Lengths

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